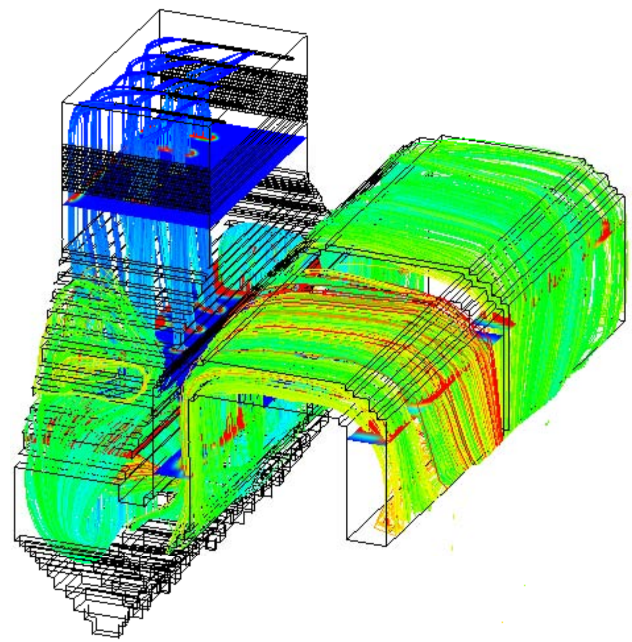
Reinhold Environmental Ltd.

2009 APC Round Table & Expo Presentation

July 12-14, 2009, in The Woodlands, TX

Testing the Use of Trona for SO_2 Removal

REACTION ENGINEERING INTERNATIONAL



APC Roundtable Meeting

July 13-14, 2009

The Woodlands, Texas

Connie Senior

Marc Cremer

Dave Wang

77 West 200 South Suite 210, Salt Lake City, Utah 84101

Presentation Overview

- A Little History
- A Little Chemistry
- A Little Engineering
- Case Study

A Little History

- Late 1980s-early 1990s, DOE funded development of lower-cost alternatives to wet FGDs
  - Several Duct Injection processes investigated: sodium and calcium sorbents for SO_2 control
  - Clean Coal Technology program at Arapahoe Station demonstrated 70% SO_2 removal with trona injection between APH and FF
- Renewed interest in “moderate” levels of SO_2 removal
  - For example, 2005 at Potomac River showed up to 80% SO_2 removal with trona injection between Economizer Outlet and H-ESP

What is Trona?

- Natural mineral: sodium sesquicarbonate
  - $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$
- Green River formation
  - Seams from 600 to 3500 ft. depth
  - 2500 square miles
  - > 100 billion tons
- Rail or truck delivery
- Bulk density: 49 lb/ft^3
- Size: 28-50 micron

A Little Chemistry

- Two steps are important for capture of SO_2 (and SO_3):
  1. Calcining

  2. Sulfation

A Little Chemistry

- Two steps are important for capture of SO_2 (and SO_3):
  1. Calcining
     - At T>275°F, trona decomposes to form Na_2CO_3 , giving off water and CO_2

$$Na_2CO_3 \bullet NaHCO_3 \bullet 2H_2O \rightarrow 3Na_2CO_3 + 5H_2O + CO_2$$

     - Calcining increases surface area, which improves reactivity
     - Higher injection temperature => higher surface area

A Little Chemistry

- Two steps are important for capture of SO_2 (and SO_3):

  2. Sulfation

     - Na_2CO_3 reacts with SO_2 and SO_3 in the flue gas

$$Na_2CO_3 + SO_2 + \frac{1}{2} O_2 \rightarrow Na_2SO_4 + CO_2$$

$$Na_2CO_3 + SO_3 \rightarrow Na_2SO_4 + CO_2$$

     - Normalized stoichiometric ratio for SO_2:

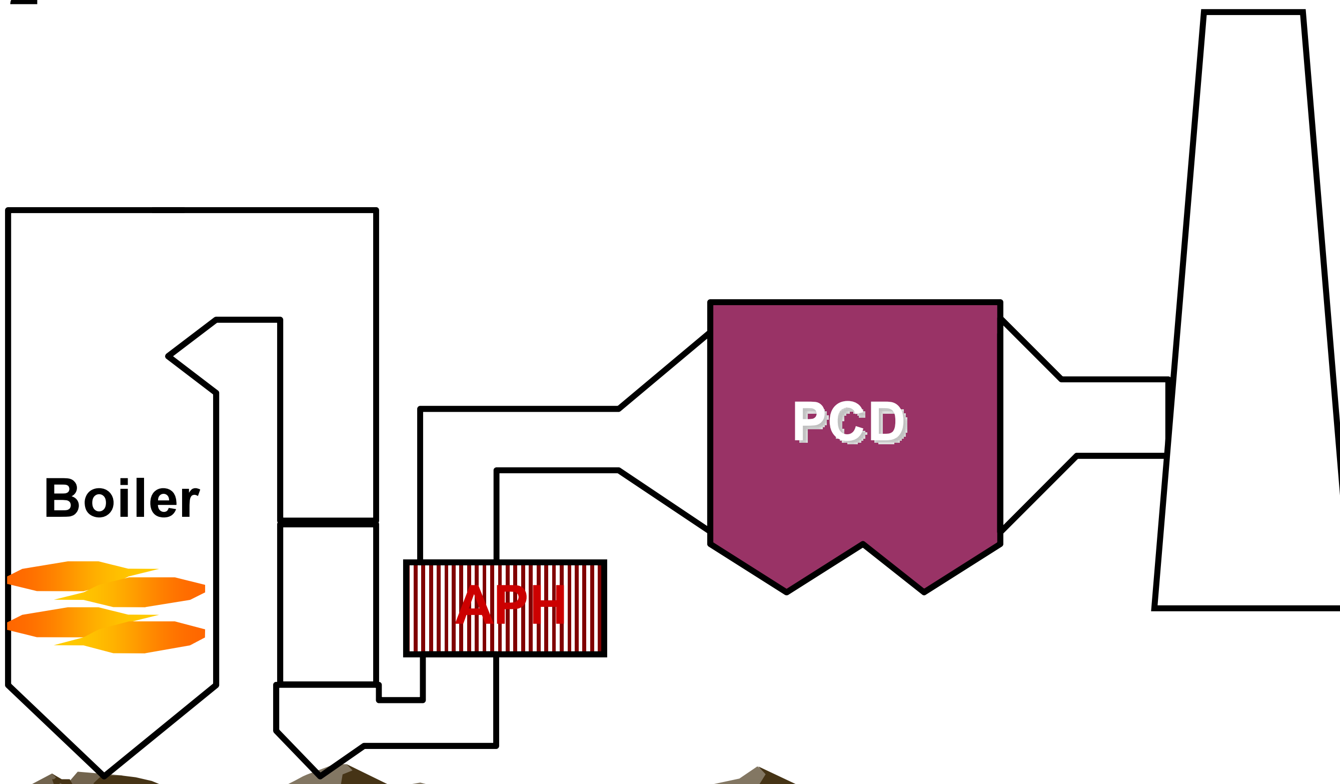
       NSR = 2 x moles Na/moles SO_2

A Little More Chemistry

- Trona also reacts with NO_x
  - 10-20% reductions in NO_x have been noted in full-scale applications for SO_2 control
  - NO_2 concentration in stack may increase because of trona

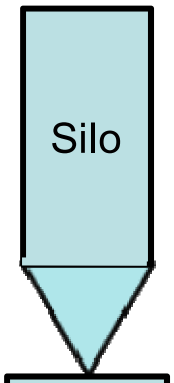
A Little Engineering

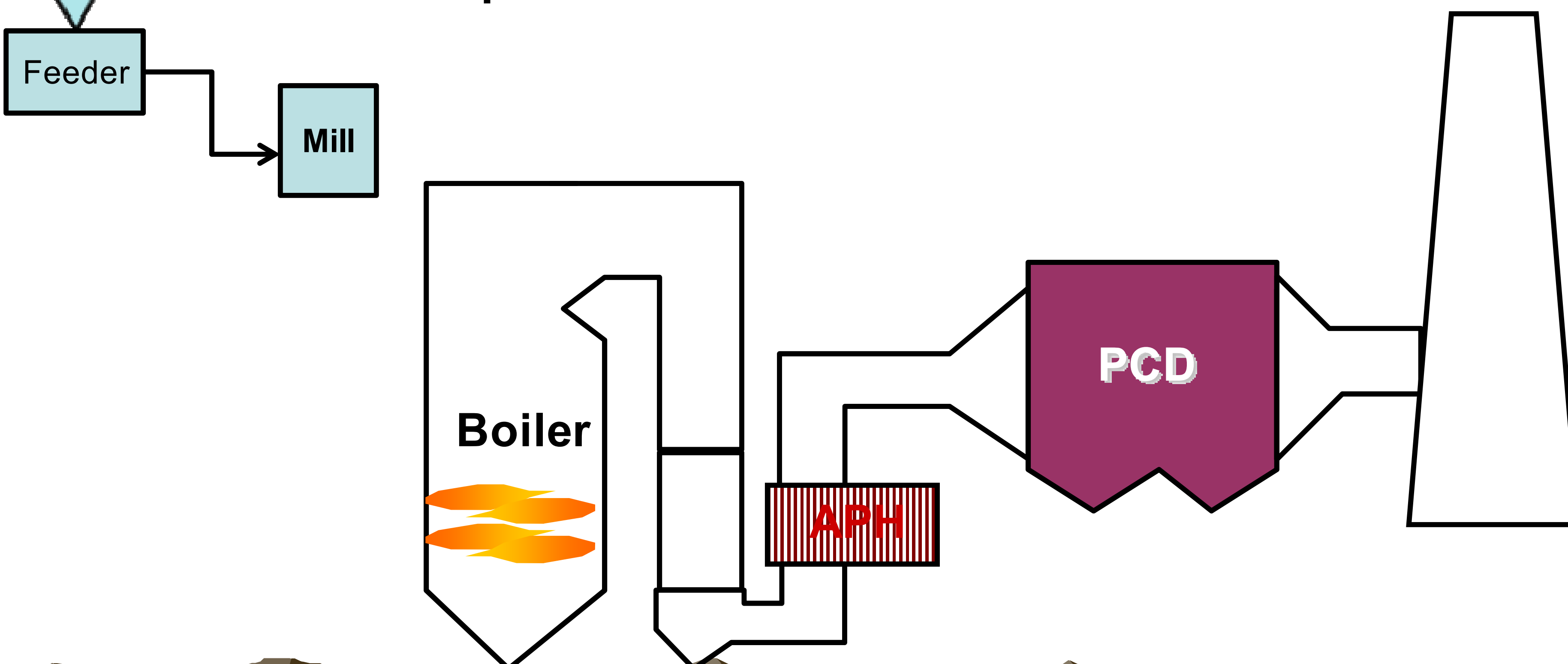
- Implementation of trona injection for SO_2 Control



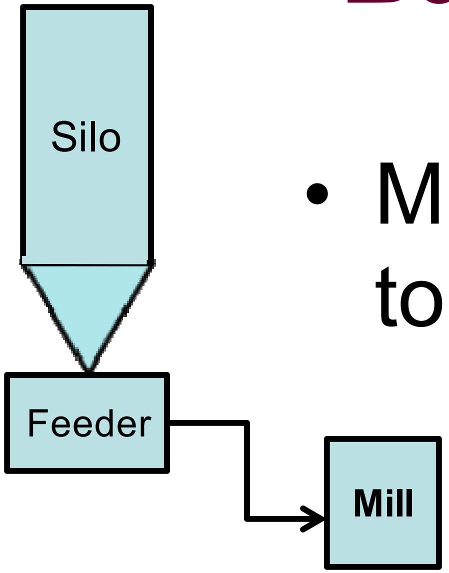
Basic Implementation

- Milling on-line often recommended to improve utilization





Basic Implementation



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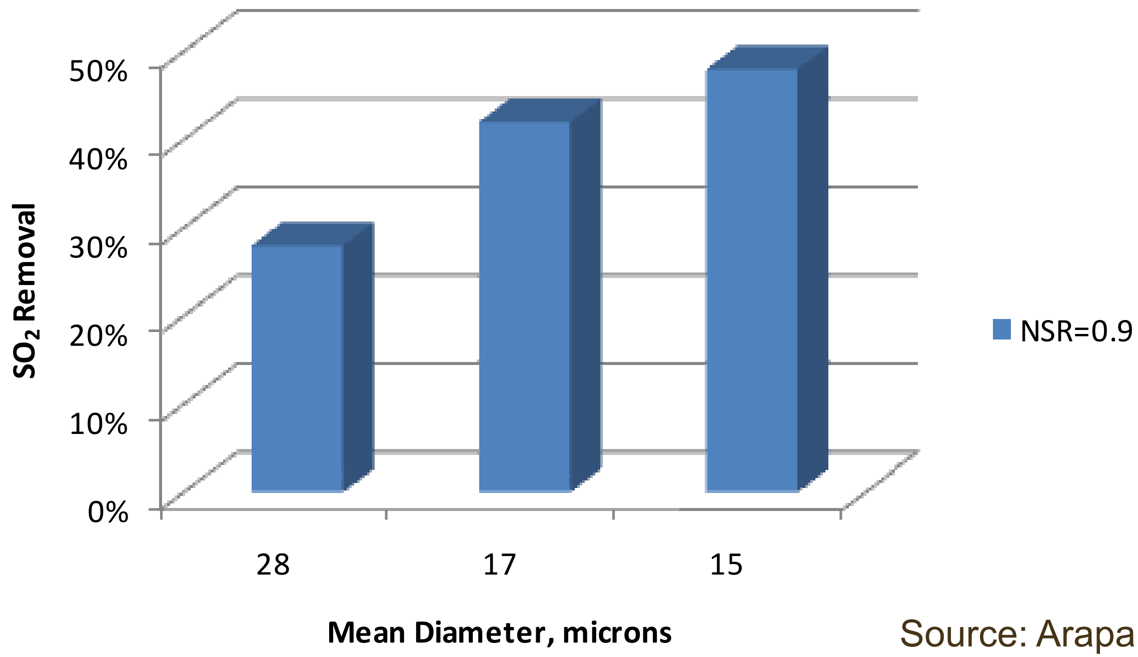
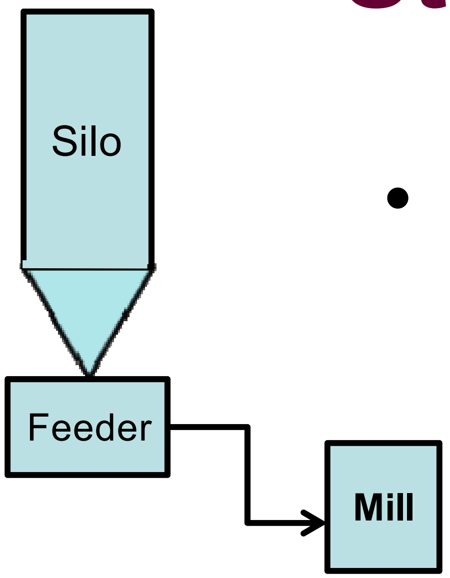


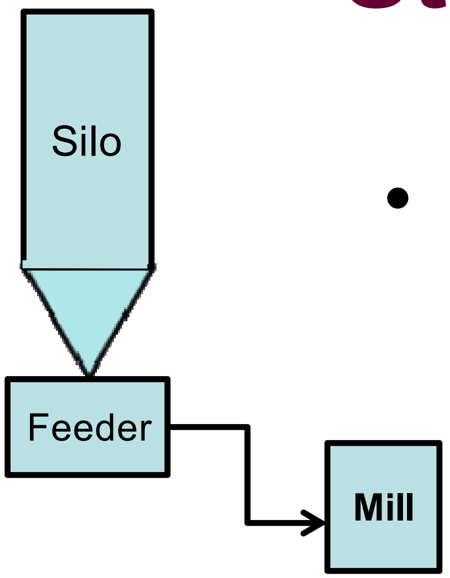
Source: Arapahoe CCT program

Storage and Handling



- Transport trona using a dilute-phase pneumatic conveying system
  - Conveying air temperature less than 140°F
  - Relative humidity less than 40%
  - Chiller and a dehumidifier recommended for the conveying air

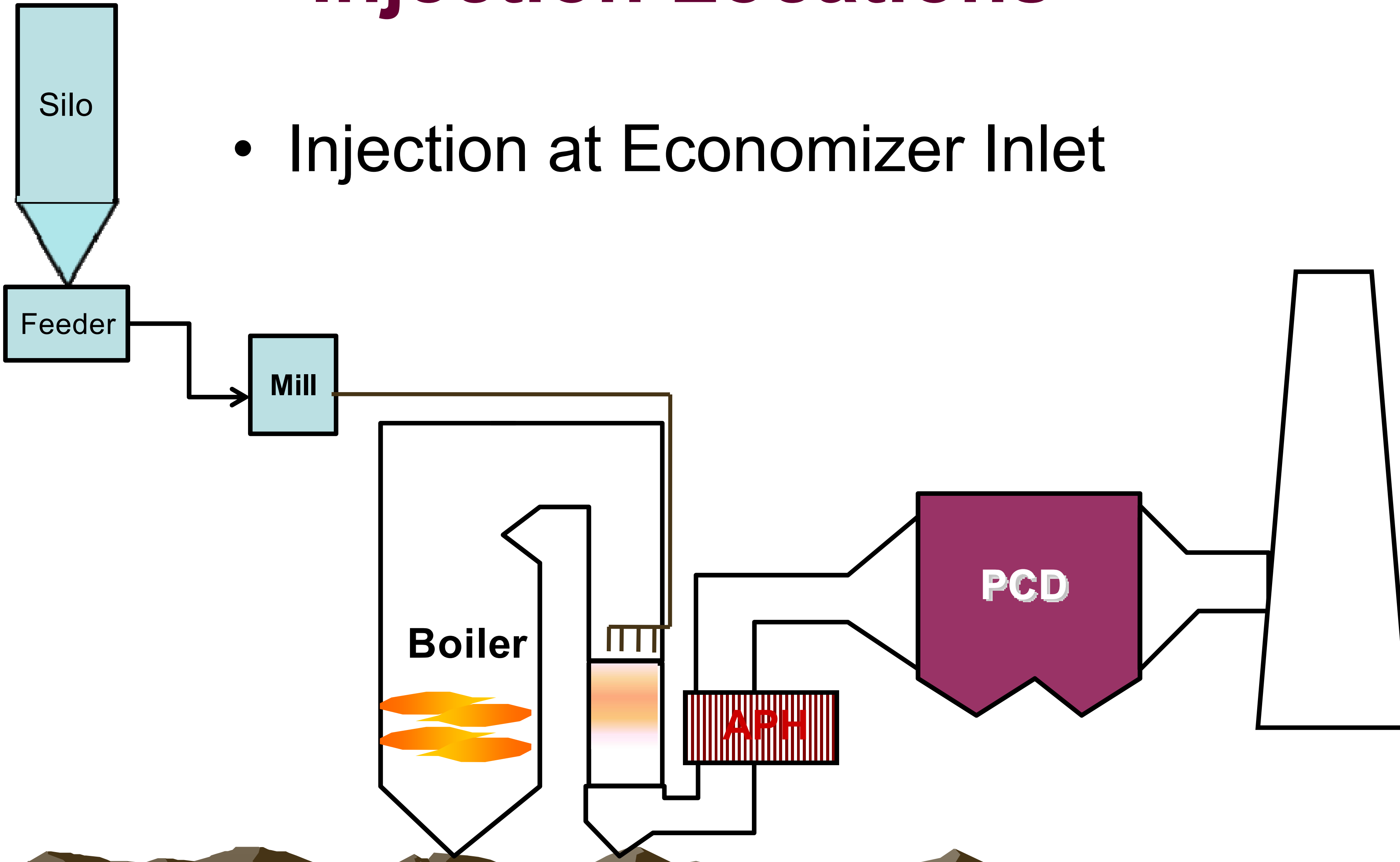
Storage and Handling



- Well-designed flow splitters, flow straighteners and static mixers in the conveying lines important to avoid plugging.
- Mass flow meters in the conveying lines can monitor flow through lances and help identify plugging

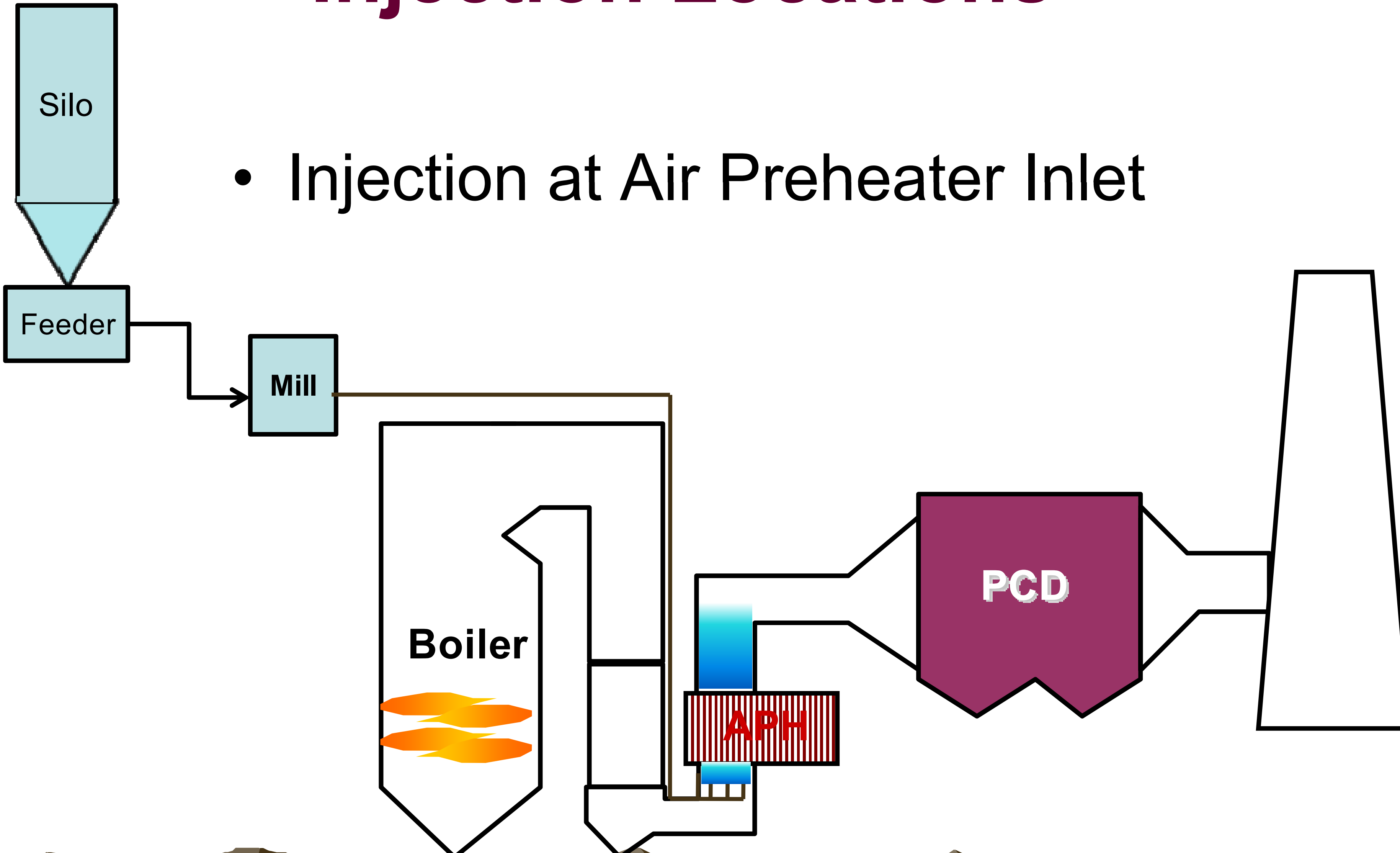
Injection Locations

- Injection at Economizer Inlet



Injection Locations

- Injection at Air Preheater Inlet



Injection Locations

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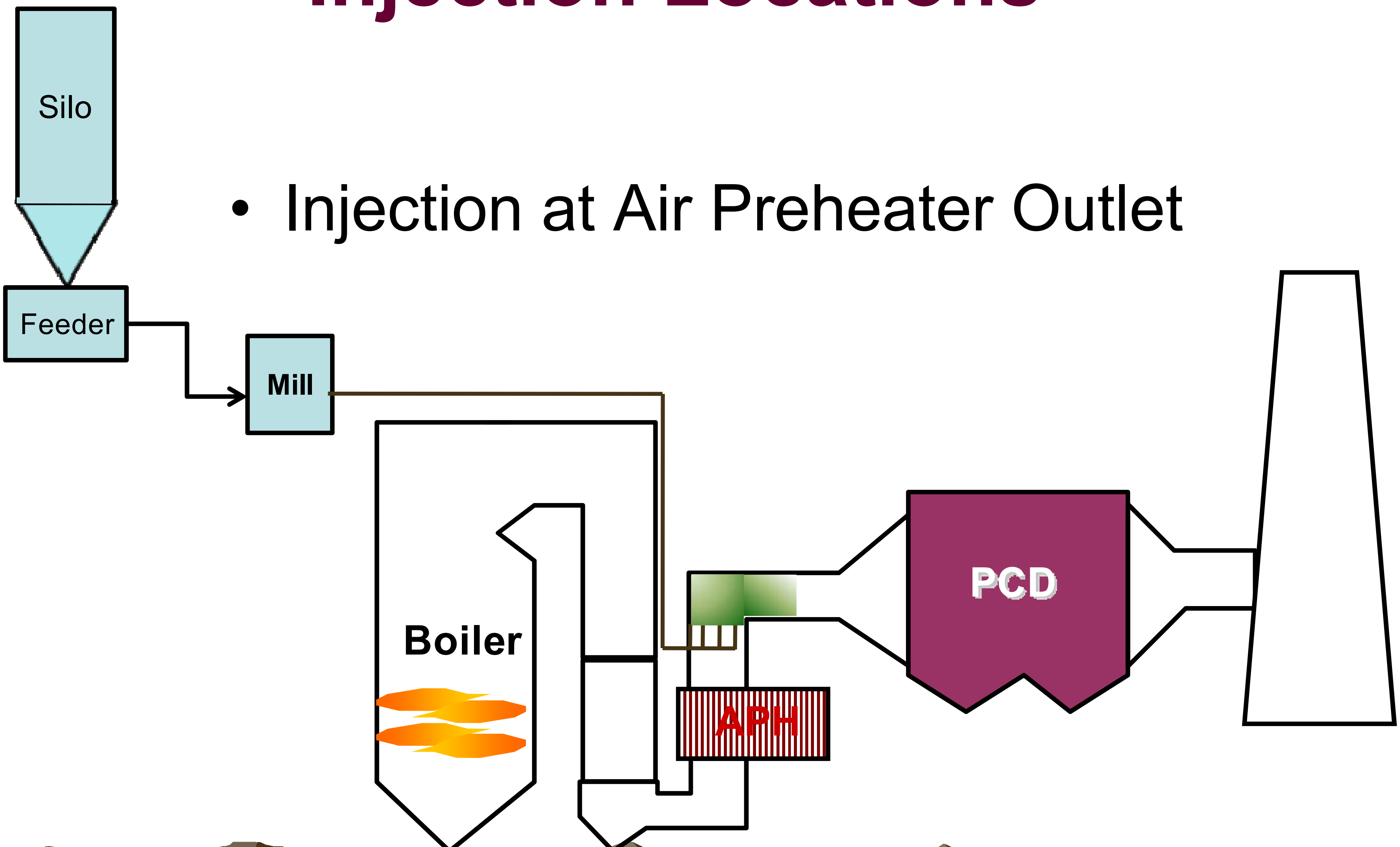


Balance of Plant Effects

- Neutral or positive effect of trona on performance of cold-side ESPs
- Trona increases sodium content of fly ash
  - Potential issues with sale of ash for concrete manufacture
  - Acceptability for landfill must be evaluated

Duct Injection Costs

- For 50-60% SO_2 reduction
- Capital Cost $15-25/kW
- O&M Cost $700-1000/ton SO_2 removed
- Design & Commissioning: under one year

Source: O'Brien & Gere, 2007

Case Study

- Site description
- Summary of trona field test results
- CFD model development
- Model-based optimization

Site Description

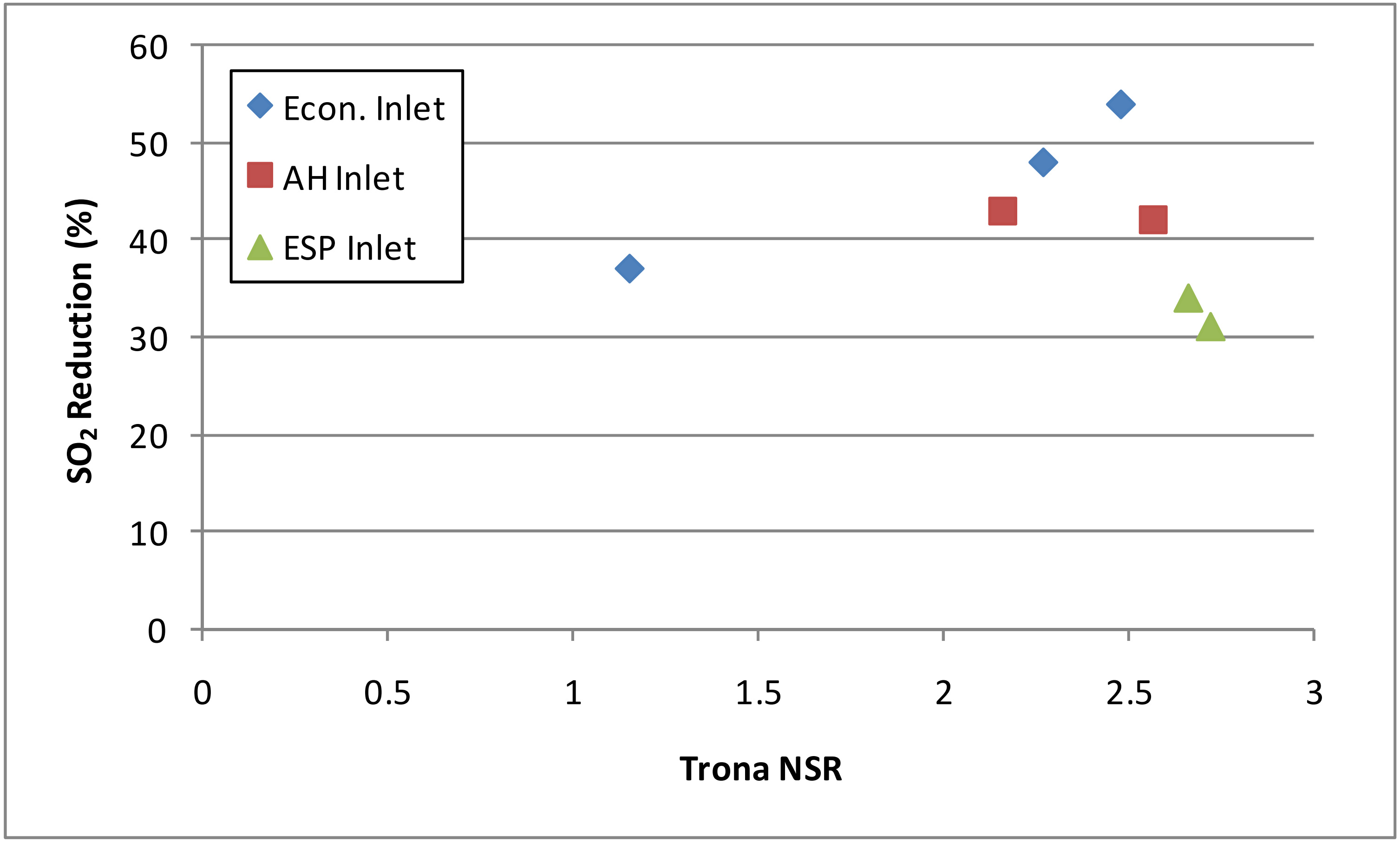
- Unit A
  - 86 MW PC, tangentially-fired, 0.7% S
  - OFA, Low-NOx burner mods, SNCR
  - Cold-side ESP
- Unit B
  - 174 MW PC, tangentially fired, 0.7% S
  - Planned OFA, Low-NOx burner mods, SNCR
  - Cold-side ESP
- State environmental regulations (SO_x)
  - < 0.37 lb SO_x/MMBtu by 2009
  - < 0.26 lb SO_x/MMBtu by 2012

Trona Field Testing

- O'Brien & Gere (May 2006 – September 2007)
- Various Sensitivities Investigated
  - Milled and unmilled
  - Injection location (Econ. Inlet, AH inlet, ESP inlet)
  - Injection rate
- Results – Both units
  - Up to 75% reduction at NSR=3.5
  - Best results with injection at economizer inlet
  - Milled performance better than unmilled

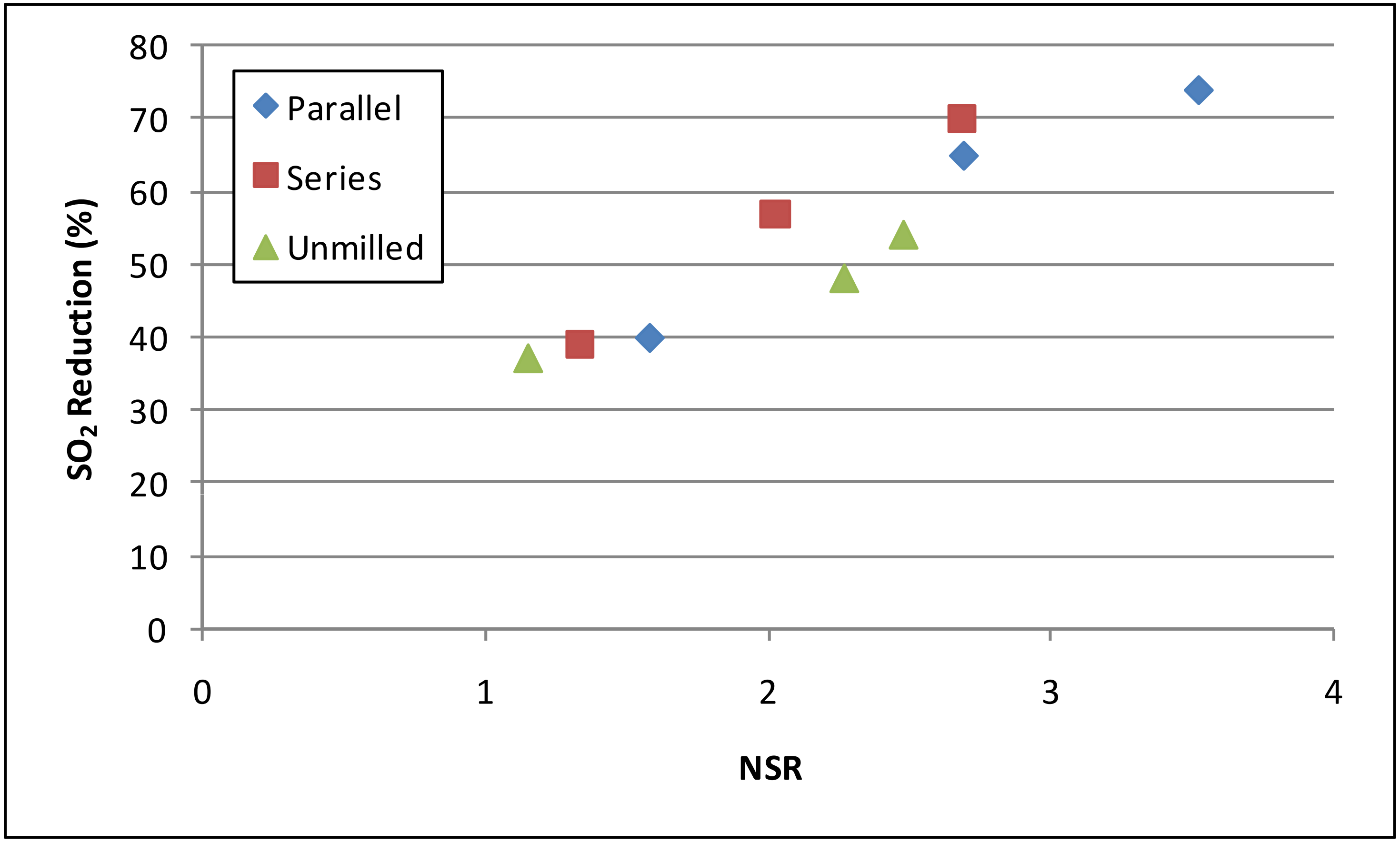
Impact of Injection Location

Unmilled Trona – Unit A



Impact of Milling

Unit A – Economizer Inlet



SO_2 Absorption Model Development

- **Trona sulfation kinetics were developed based on packed-bed pilot-scale data**
  - Davis, W.T., Keener, T.C. "Chemical Kinetic studies on dry sorbent",1982.

- **Trona particles ($Na_2CO_3.NaHCO_3.2H_2O$) endure an endothermic decomposition and exothermic SO_2 absorption**

$$Na_2CO_3.NaHCO_3.2H_2O \rightarrow 3/2Na_2CO_3 + 1/2CO_2(g) + 5/2H_2O(g)$$

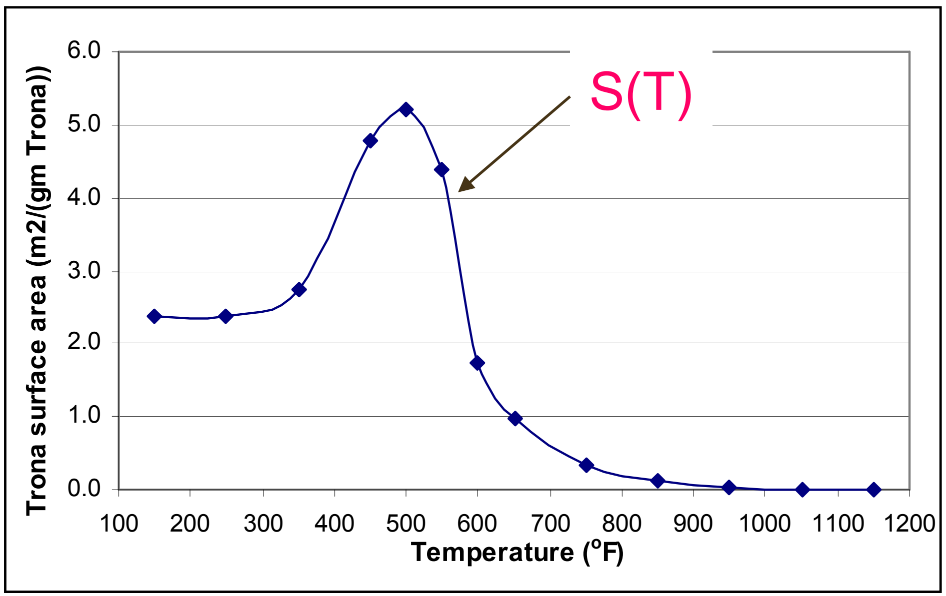
$$Na_2CO_3 + SO_2(g) + 1/2O_2(g) = Na_2SO_4 + CO_2(g)$$

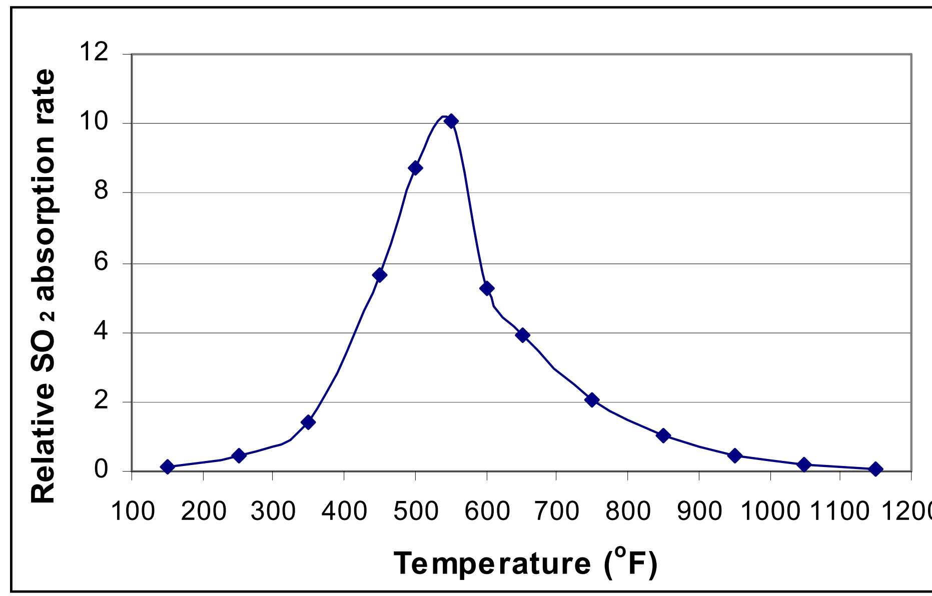
- **The decomposition kinetics are dependent on the Trona particle temperature -- Initiates at 300°F**

Trona Particle Sulfation Kinetics

$$R_{SO2} = A.\ P_{SO2}.S(T).(1.0\text{-}XB)^2.exp(-E/RT)$$

$$R_{SO2} = m_{SO2.max}.\ dXB/dt$$



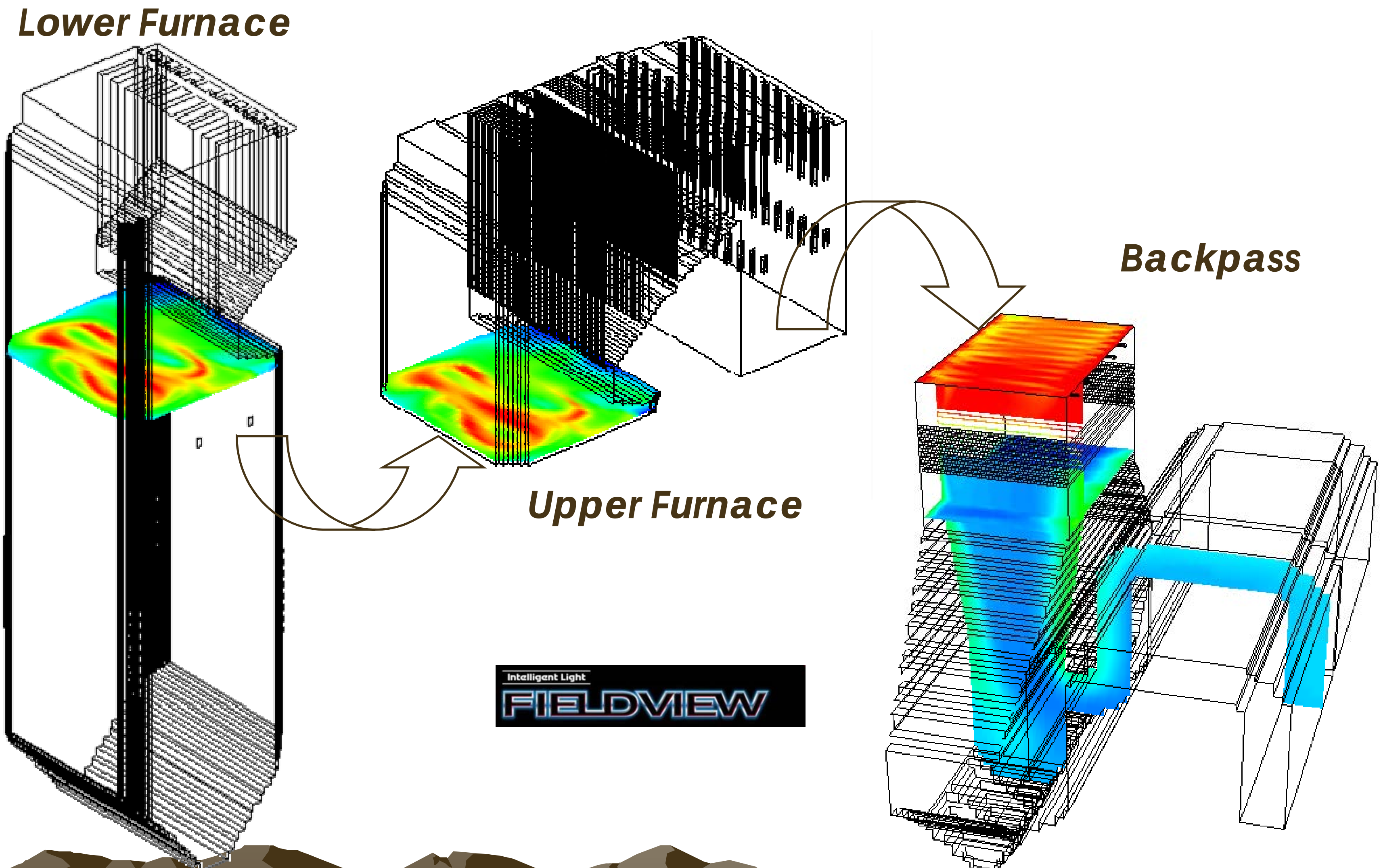


Source: Davis, Keener, 1982

Trona Model integration with CFD

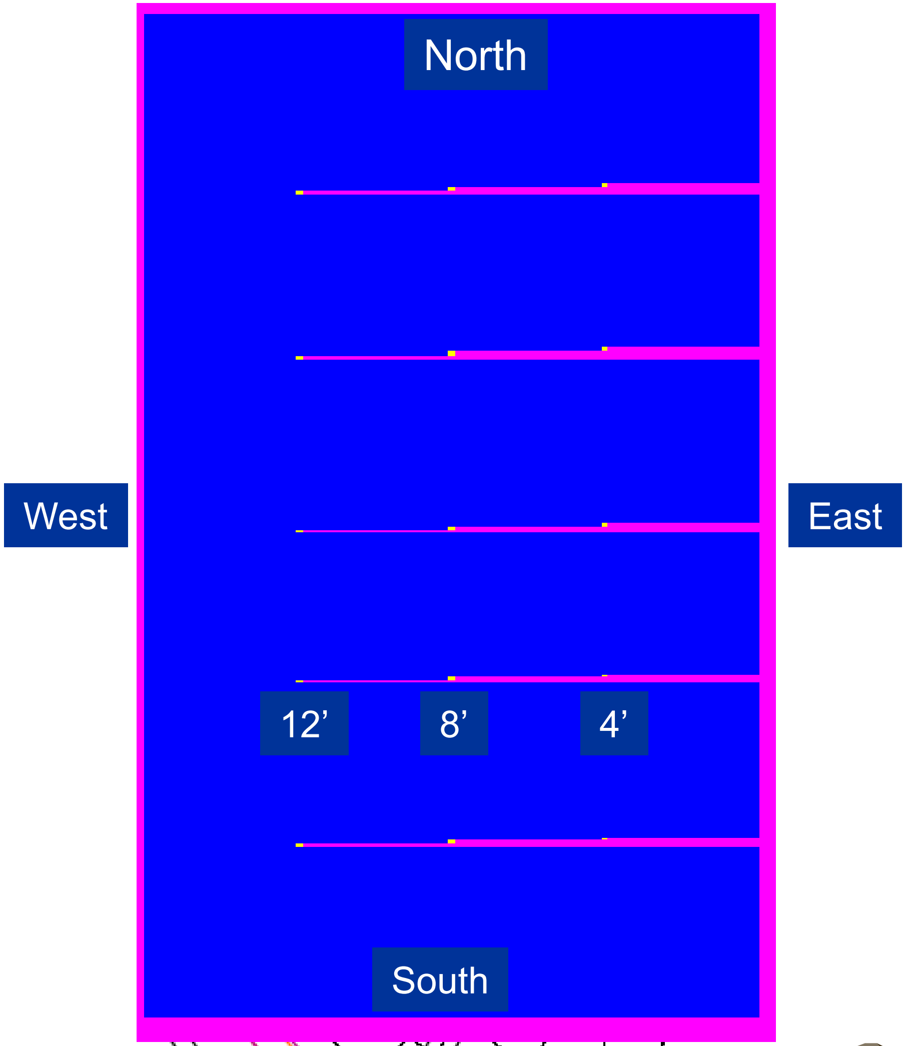
- **Integration into REI's CFD model *GLACIER***
  - Solve trona particle momentum, energy equations along the trajectories
  - Determine trona particle decomposition and SO_2 absorption rate
  - Couple the trona decomposition products and SO_2 absorption with gas phase
  - Solve the SO_2 gas phase transport
- **SO_2 removal is determined by:**
  - SO_2 concentration in the flue gas
  - NSR
  - Trona particle coverage
  - Trona particle size (external mass transfer)
  - Gas/particle temperature
  - Residence time

Model-Based Approach



Trona Test Lance Configuration

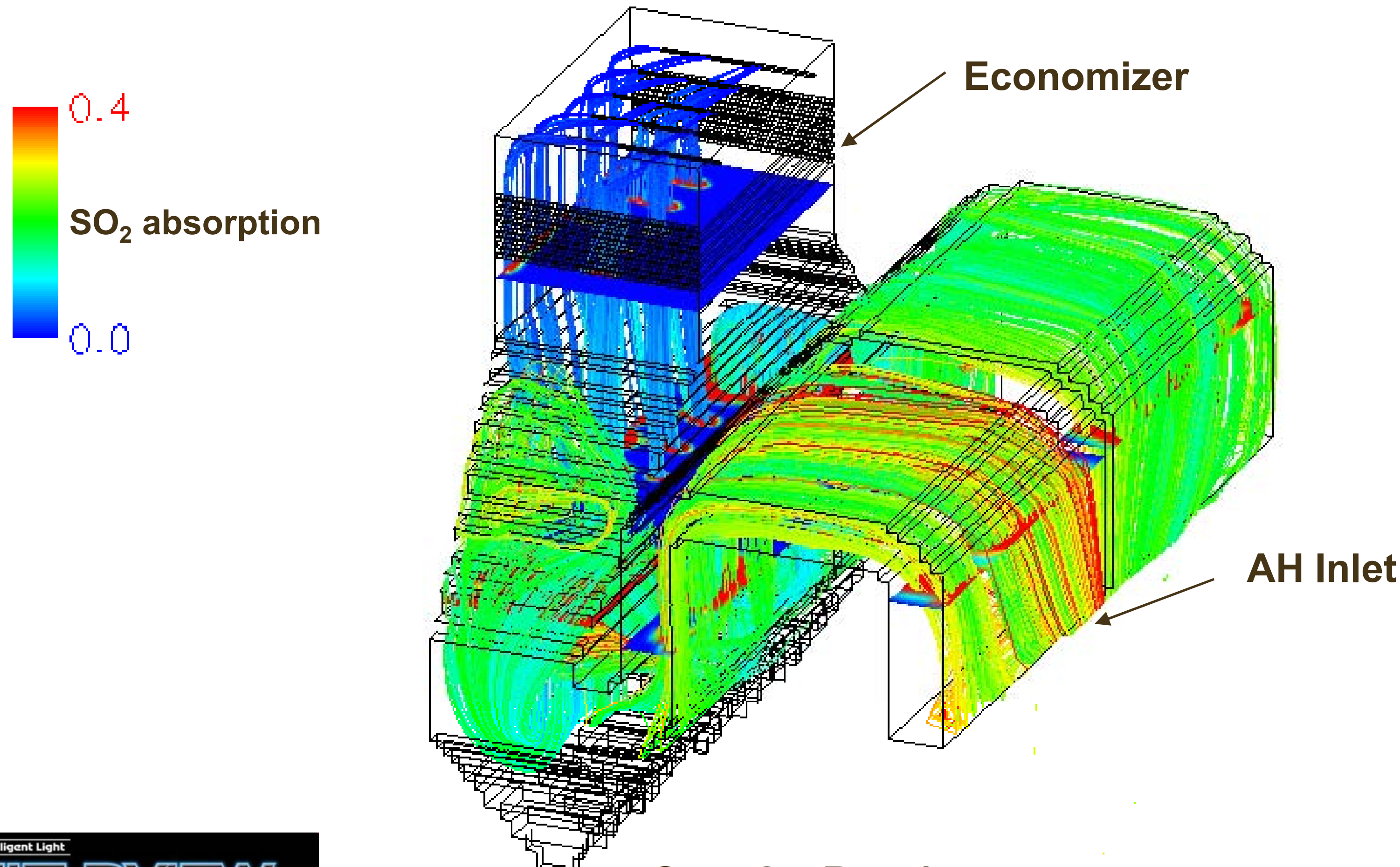
Unit A



- Economizer inlet injection
- 15 lances – 1” and 1-1/4” ID
  - 15 lances for parallel mill operation
  - 9 lances for series mill operation (south duct)

Trona Particle Trajectories

Unit A – Economizer Inlet to AH Inlet

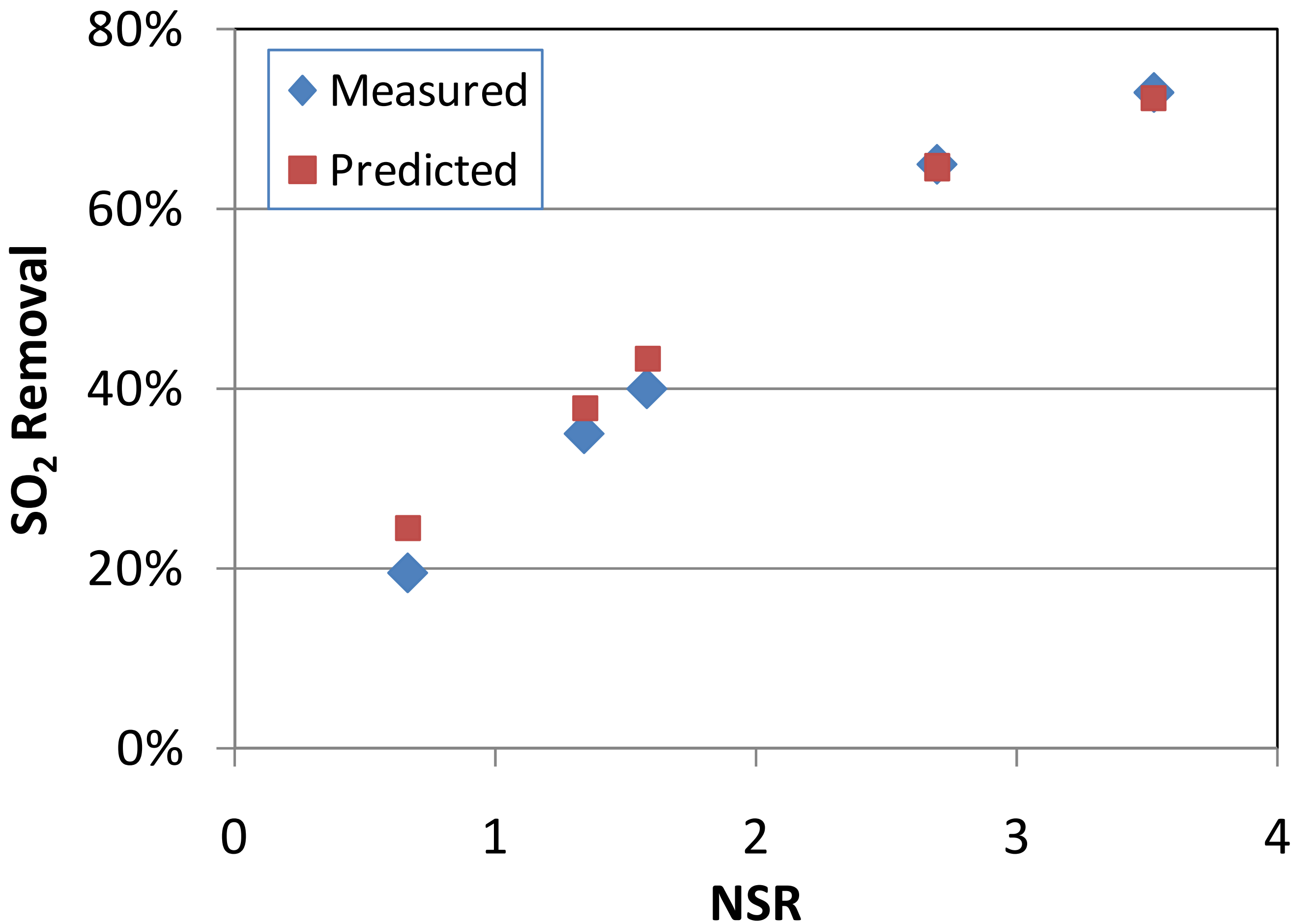


Case 2 – Run 4

Intelligent Light FIELDVIEW

Model Verification

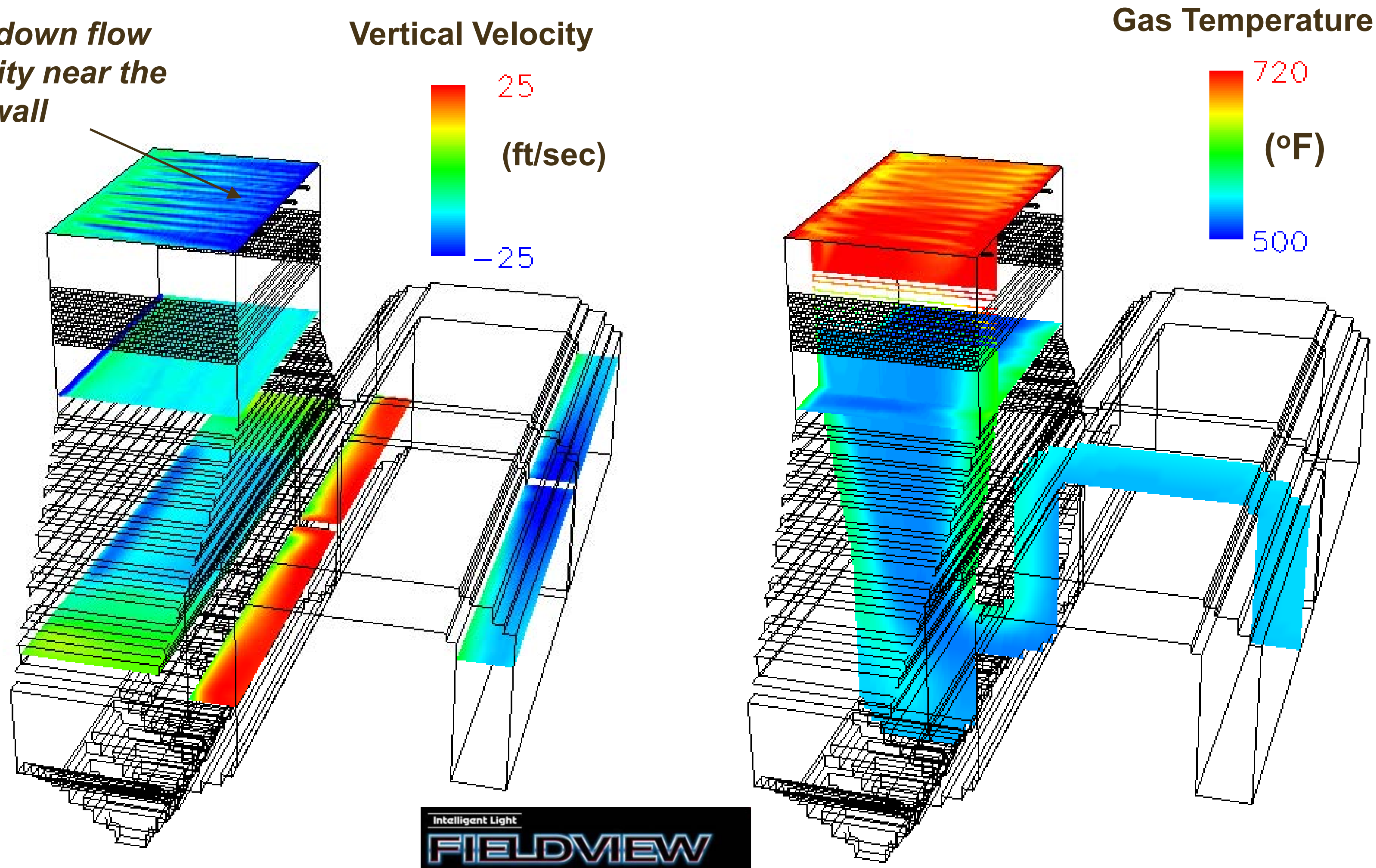
Unit A – Economizer Inlet



Flue Gas Velocity and Temperature

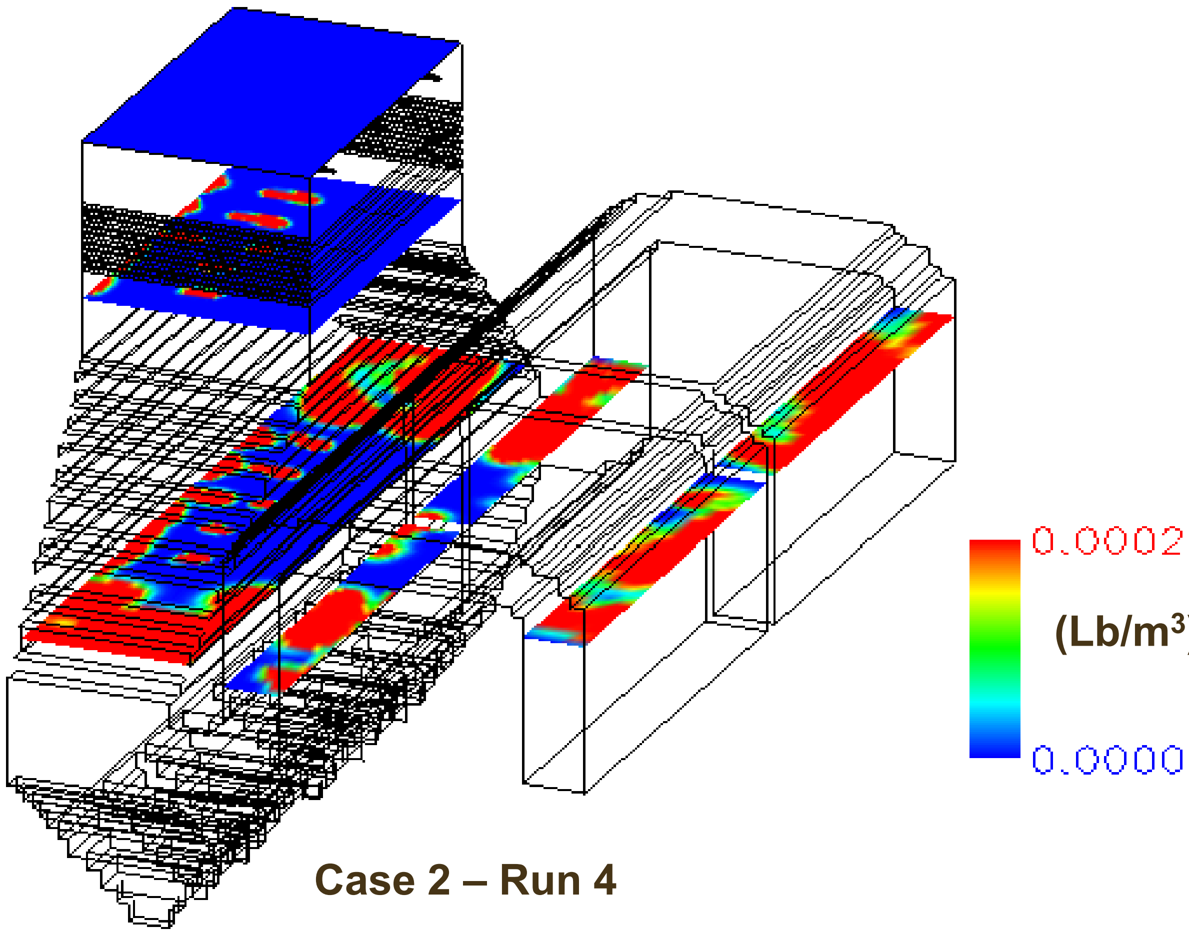
Unit A

High down flow velocity near the east wall



Sorbent Mass Density

Unit A

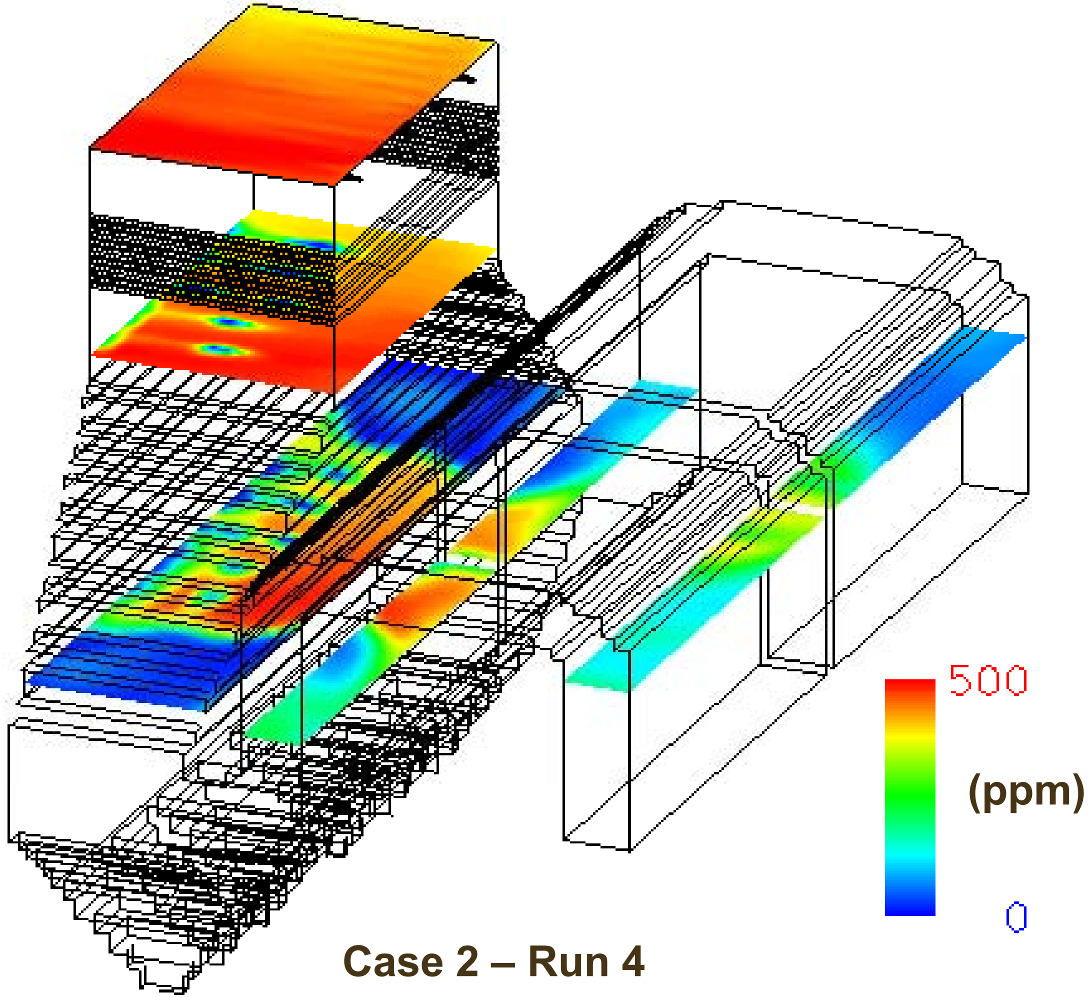


Case 2 – Run 4

FIELDVIEW

SO_2 Concentration

Unit A



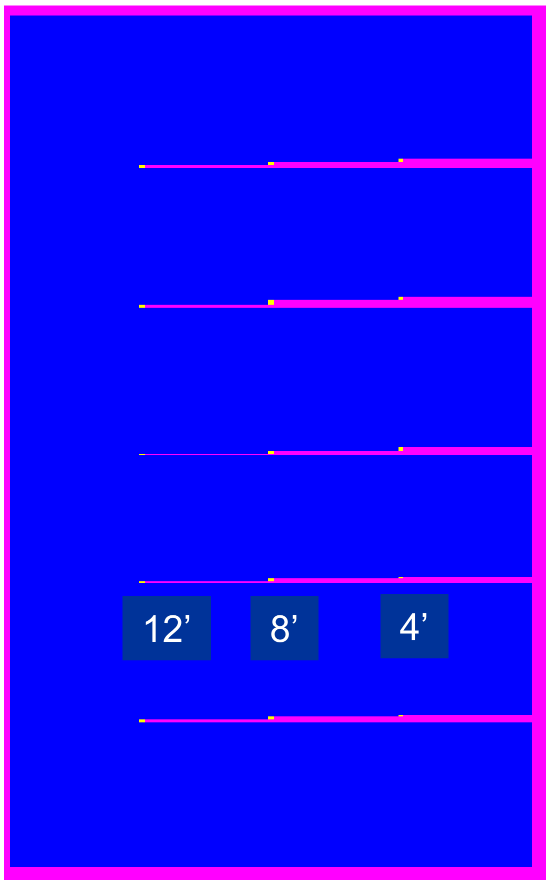
Case 2 – Run 4

Intelligent Light FIELDVIEW

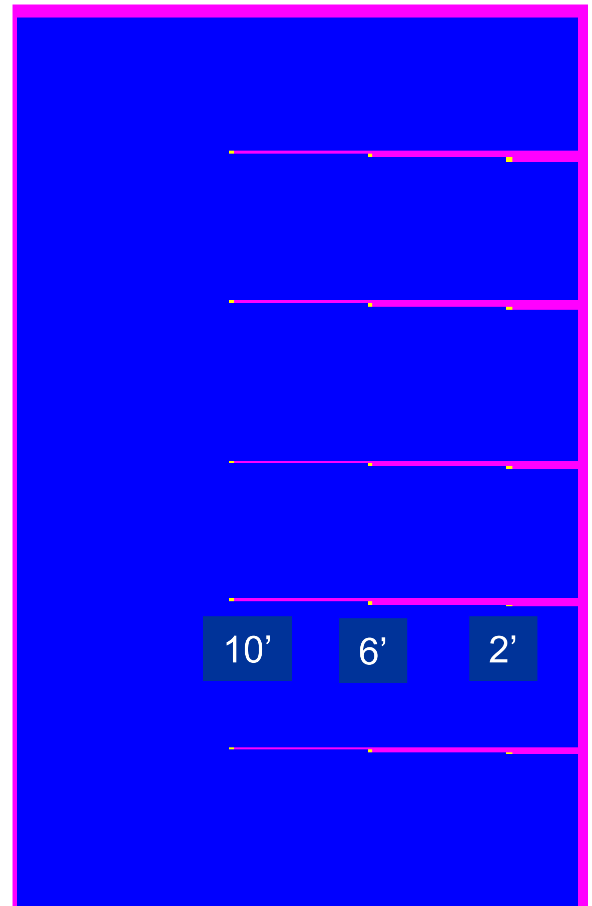
Simulated Injection Strategies

Unit A

EL 100' : Strategy 1
EL 90' : Strategy 5



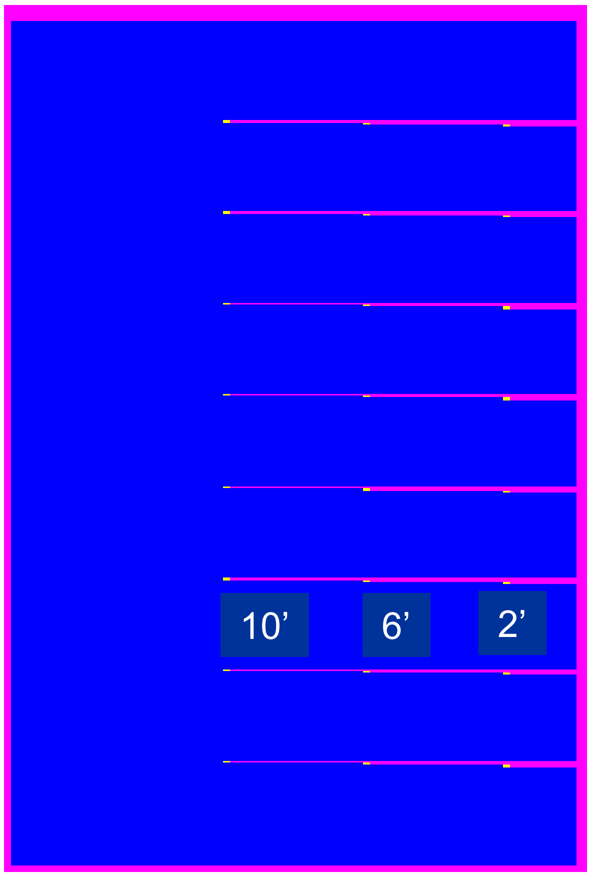
EL 100' : Strategy 2
EL 90' : Strategy 6



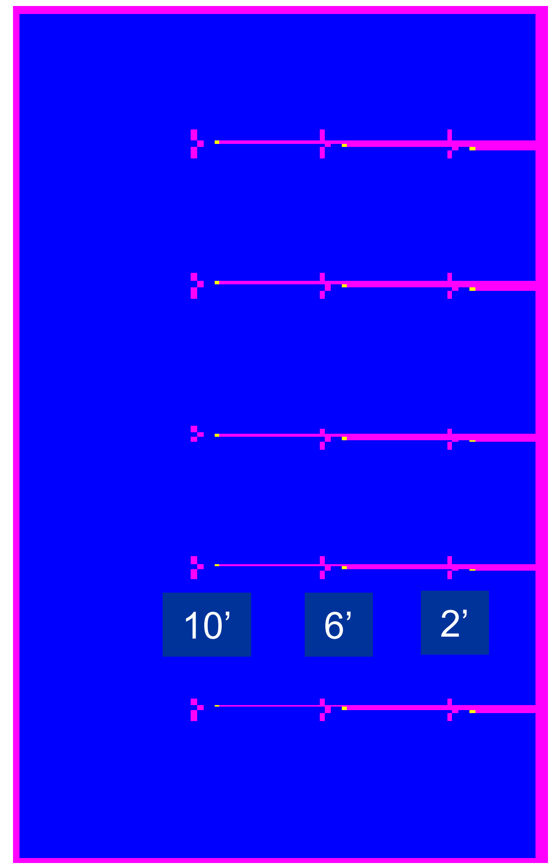
Simulated Injection Strategies

Unit A

EL 100’ : Strategy 3 (24 lances)

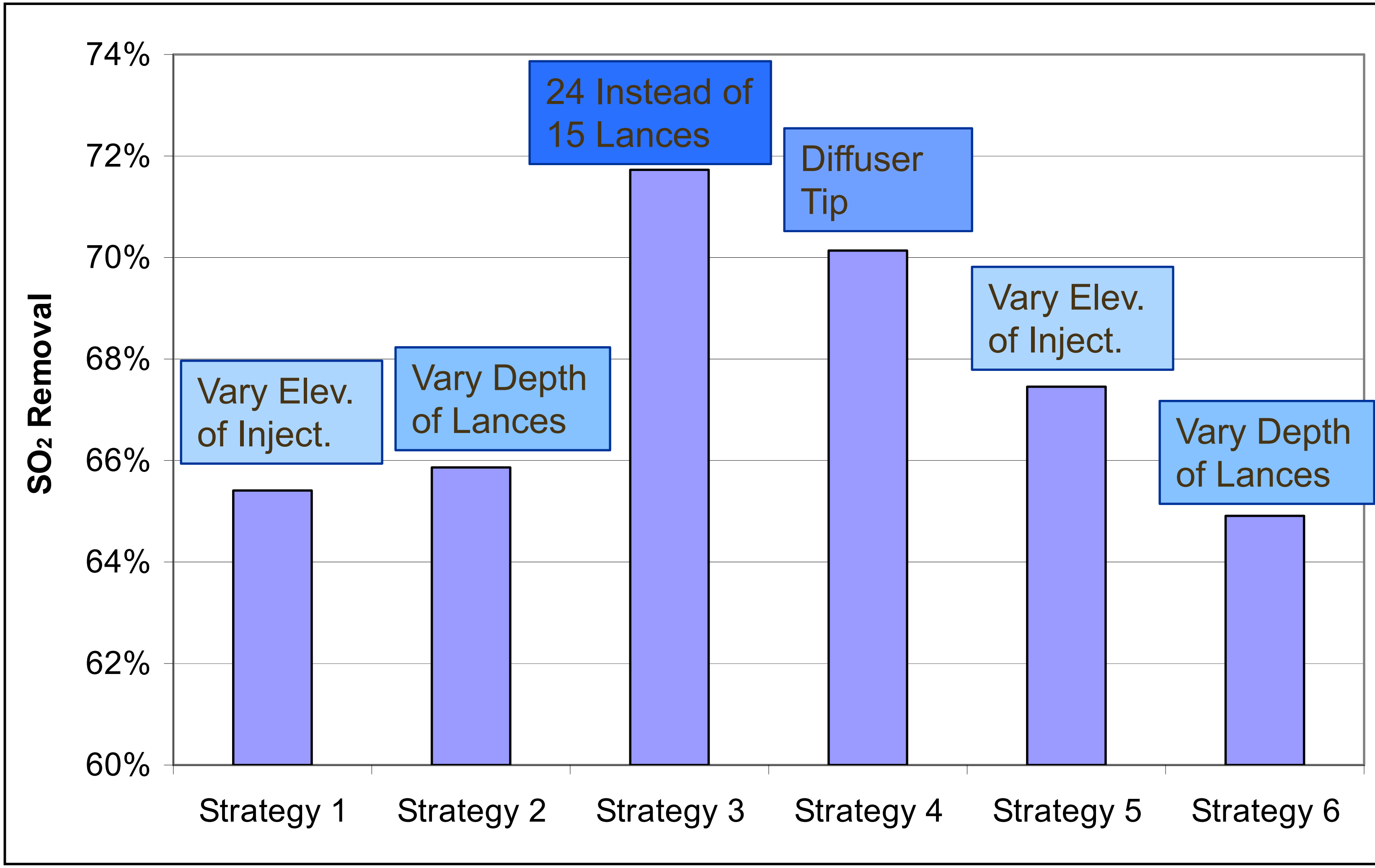


EL 100’ : Strategy 4 (Diffuser tip)



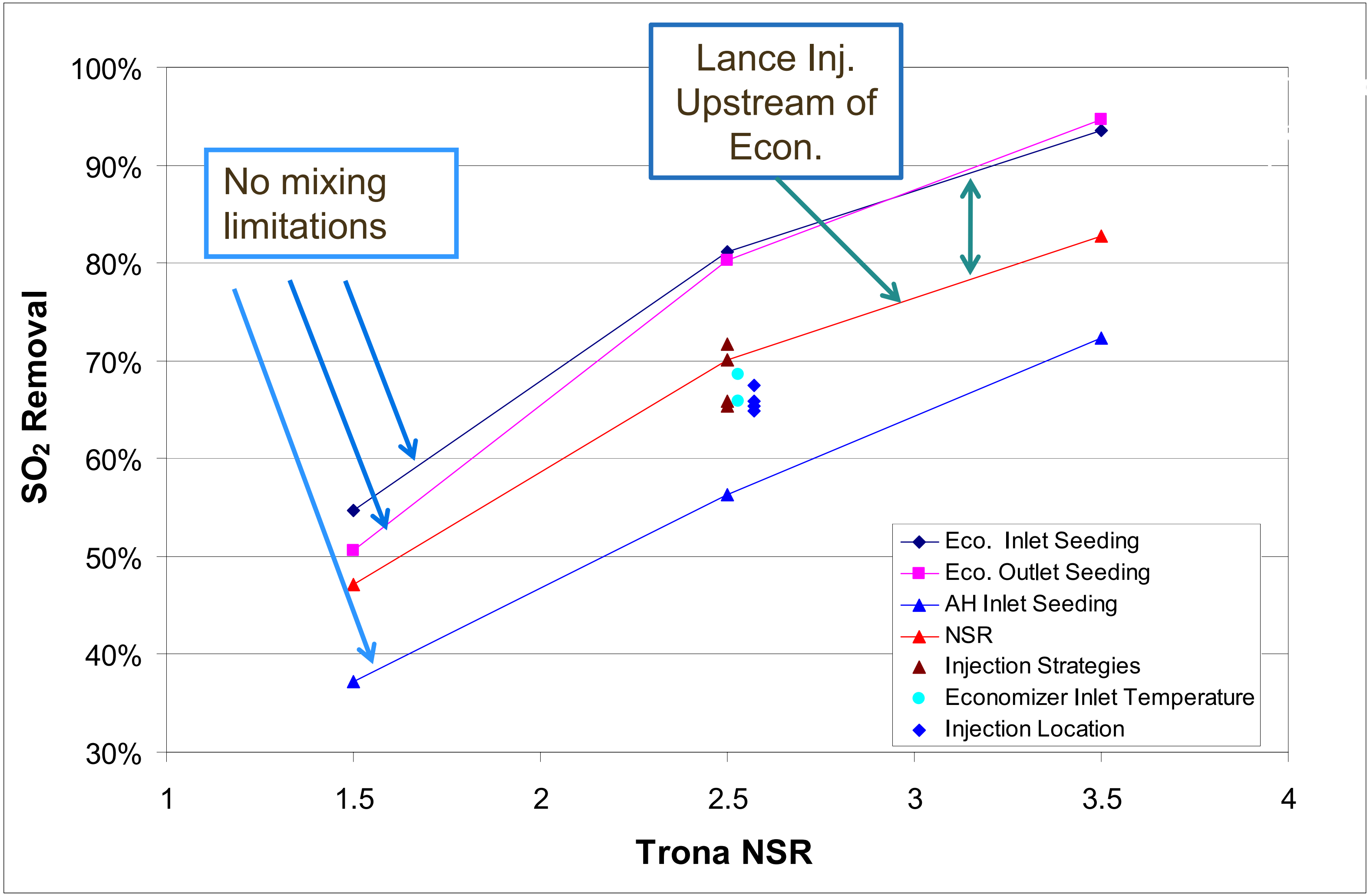
Results – Injection Strategies

Unit A – Economizer Inlet (NSR=2.5)



Results of Parametric Cases

Unit A



Summary of Case Study

- **Field testing of trona injection for SO_2 control in an 86 MW unit shows:**
  - **SO_2 reduction improves when moving injection from the economizer exit to the inlet**
  - **SO_2 reduction improves when milling from 30 μm to approximately 12 μm D50**
  - **SO_2 reduction measured up to 74% with NSR = 3.5 with milled trona**
- **CFD based model for SO_2 capture by duct injection of trona was developed**
- **Application of model to two coal-fired units shows good agreement with field test results**
- **Prediction of parametric dependencies in the 86 MW shows:**
  - Similar SO_2 removals for injection immediately upstream or downstream of economizer - removal is limited by the trona coverage
  - Potential for 80% SO_2 reduction at NSR=2.5 assuming no distribution constraints
  - 83% reduction is achievable at NSR=3.5 with simulated injection strategies

QUESTIONS?